ENERGY AND WIDTH MEASUREMENTS OF THE PIONIC 2p-1s TRANSITION IN ^{23}Na *

G. H. Miller†, M. Eckhause, W. W. Sapp, and R. E. Welsh

Department of Physics, College of William and Mary

Williamsburg, Virginia, U.S.A.

*This work was supported in part by the National Aeronautics and Space Administration.

†National Science Foundation Predoctoral Trainee 1967-68.

ABSTRACT

New measurements of the energy and natural linewidth of the pionic 2p-1s x-ray transition and of the energy of the muonic 2p-1s x-ray transition in ^{23}Na have been performed. A high-resolution Ge(Li) spectrometer was used, resulting in more precise measurements than previously reported. Comparisons are made with the theoretical predictions of the Ericsons.

Recent measurements[1,2] of the natural linewidths of pionic 2p-1s transitions have shown a discrepancy between theoretical and measured values as Z increases. We present here new and more precise measurements of the pionic 2p-1s transition energy and width in ^{23}Na.

The data were obtained using a 100 MeV negative pion beam at the NASA Space Radiation Effects Laboratory (SREL). This beam was focused into a scintillation counter telescope, and coincidence requirements insured that pulses were stored in a 1600-channel pulse height analyzer only when a timing coincidence existed between a π-stop signal and a detector signal. The x-rays were detected in a 30 cm^3 coaxial Ge(Li) detector coupled to a cooled FET preamplifier which provided good resolution and minimization of count rate effects.[3] The resolution as determined from muonic x-rays accumulated simultaneously with the pionic x-rays was approximately 2.2 keV FWHM at 250 keV. ^{182}Ta and ^{203}Hg calibration lines at 222.144 and 279.160 keV, respectively, exhibited resolutions of 2.1 and 2.4 keV FWHM when accumulated under beam conditions before and after each pion run.

Four separate pion runs were taken and one muon run was accumulated for background analysis. Approximately 6500 pionic 2p-1s events were recorded. The summed data of the four runs are plotted in Fig. 1.

The energy of the pionic 2p-1s transition was determined with a least squares fit of the data to a Lorentzian function with a linear background term, while the natural linewidth was determined by using a Voigt profile "search" technique.[4] (A Voigt profile is the convolution integral of a Gaussian and a Lorentzian function.) For each run, the instrumental line

width was determined with a least squares fit of the muonic 2p-1s transition data in the pionic runs to a Gaussian function with a linear background term. There was sufficient muon contamination in the pion beam to make this a sensitive test of instrumental linewidth.

The strong interaction nuclear force shift E_{nuc} is the difference between the experimentally-determined energy for the pionic 2p-1s transition and the calculated energy. The calculated energy is the energy as predicted by the Klein-Gordon equation with corrections for finite size and vacuum polarization. The energy shift due to the vacuum polarization correction was calculated after Mickelwait and Corben,[5] and the finite size correction by the method of Pustovalov[6] using the nuclear radius determined by Backenstoss, et al.[7]

The results of this work are summarized in Table I and compared to the other most recent measurements. The errors quoted in this experiment include statistical uncertainties, as well as uncertainties in the background analysis and in the linearity of the spectrometer. Also included in this table are theoretical predictions[8,9] for the natural linewidth and the nuclear force shift based on the theory of the Ericsons.[10,11] The agreement is poor, in contrast to the results reported[4] for lower Z pionic x-rays.

Measurements of pionic linewidths and energies may be subject to uncertainties when nuclear γ-rays, induced by pion or muon capture or by inelastic pion scattering, fall close to the pionic x-ray energy.[2,12] No such γ-rays were seen in ^{23}Na for the pure muon beam. In addition, a

search for contaminating γ-ray transitions arising from the possible products of pion capture or pion scattering failed to reveal a γ-ray in the neighborhood of 280 keV.[13] It therefore appears unlikely that the pionic 2p-1s line contains an admixture of narrow linewidth contaminants.

We would like to thank Dr. R. J. Harris, Jr., Dr. W. B. Shuler, Dr. D. A. Jenkins, and Mr. D. G. Eisenhut for aid rendered during the experiment and data analysis, and Dr. R. T. Siegel and the staff of SREL for their support.

TABLE I

Pionic and muonic 2p-1s x-ray measurements in ^{23}Na. Theoretical and measured values of the pionic natural linewidth and nuclear force-shift are compared. Energies are in keV.

	E_μ(2p-1s)	E_π(2p-1s)	Γ_N(2p-1s)	E_{nuc}
Berkeley[a]	249.6 ± 0.5	277.2 ± 1.0	4.6 ± 3.0	49.8 ± 1.4
CERN[b]	250.21 ± 0.15	276.2 ± 1.0	10.3 ± 4.0	52.4 ± 1.0
W & M	250.4 ± 0.1	277.7 ± 0.5	6.2 ± 1.2	51.0 ± 0.5
Ericsons[c]	----	----	33.57	68.36 ± 10.42

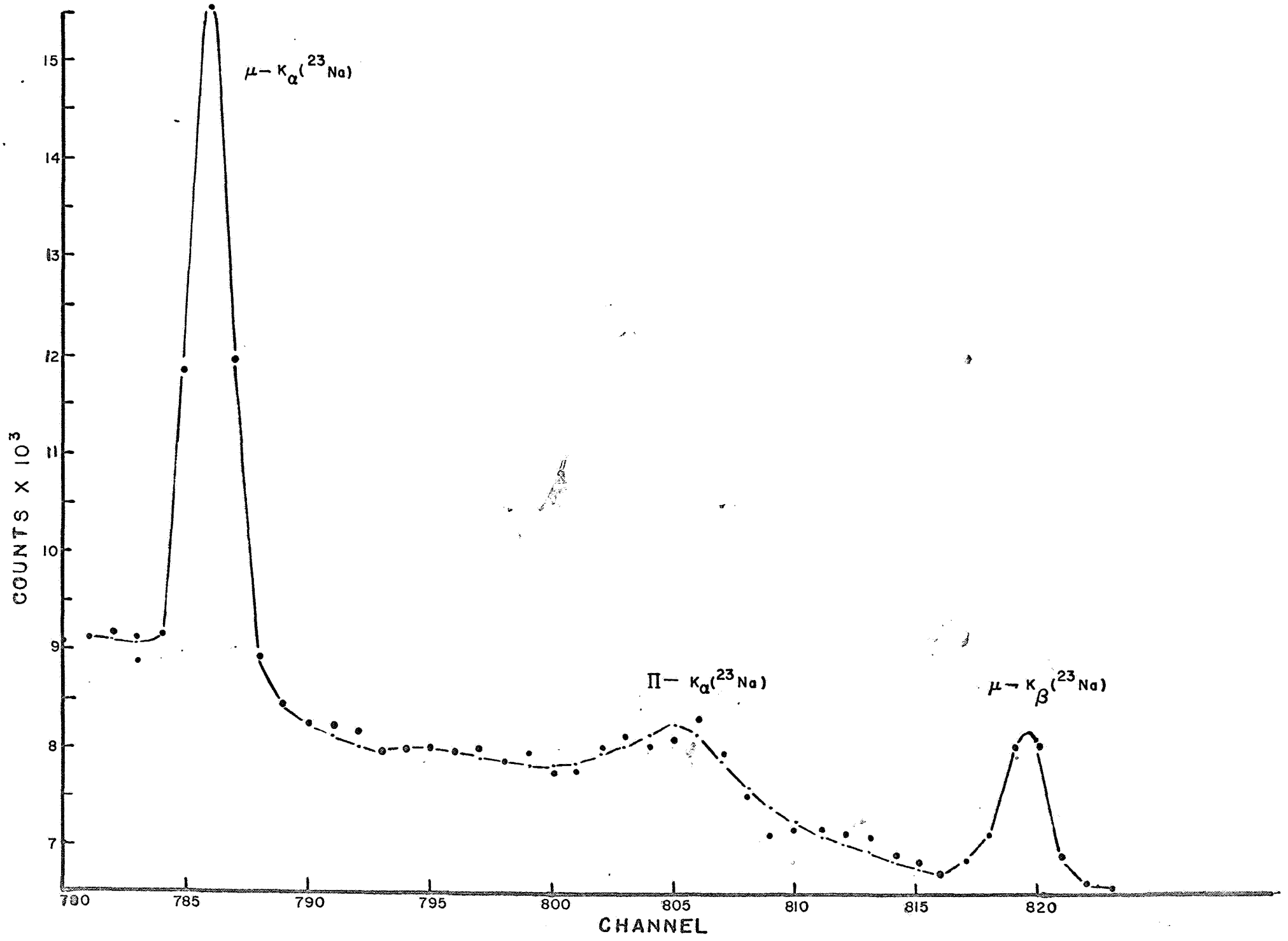
[a] See Reference 1

[b] See Reference 2

[c] See References 8 - 11

FIGURE CAPTION

Fig. 1. Summed data from four pion runs showing μ-K_α, μ-K_β, and π-K_α lines in ^{23}Na. Each point represents the sum of the data in four adjacent channels.


μ− Kα(23Na)
Π− Kα(23Na)
μ− Kβ(23Na)
COUNTS X 10³
CHANNEL
15
14
13
12
11
10
9
8
7
780
785
790
795
800
805
810
815
820

REFERENCES

1) D. A. Jenkins, R. Kunselman, M. K. Simmons and T. Yamazaki, Phys. Rev. Letters 17, 1 (1966); D. A. Jenkins and R. Kunselman, Phys. Rev. Letters 17, 1148 (1966).

2) G. Backenstoss et al., Phys. Letters 25B, 365 (1967).

3) R. J. Harris, Jr., College of William and Mary Report No. 8, 1967 (unpublished).

4) R. J. Harris, Jr., W. B. Shuler, M. Eckhause, R. T. Siegel and R. E. Welsh, Phys. Rev. Letters 20, 505 (1968).

5) A. B. Mickelwait and H. C. Corben, Phys. Rev. 96, 1145 (1954).

6) G. E. Pustovalov, Zh. Eksperim i Teor. Fiz. 36, 1806 (1959) [translation: Soviet Phys. - JETP 9, 1288 (1959)].

7) G. Backenstoss, et al., Phys. Letters 25B, 547 (1967).

8) R. J. Harris, Jr., Thesis, College of William and Mary Report No. 12, 1968 (unpublished).

9) W. B. Shuler, Thesis, College of William and Mary Report No. 13, 1968 (unpublished).

10) M. Ericson, Compt. Rend. 257, 3831 (1963).

11) M. Ericson and T. E. O. Ericson, Ann. Phys. (NY) 36, 323 (1966).

12) R. A. Carrigan, Jr., et al., Phys. Rev. 169, 963 (1968).

13) C. M. Lederer et al., "Table of Isotopes", Sixth Edition, John Wiley and Sons, New York 1967.